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Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

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TESTING OF ALBERTA SPRUCE AND PINE
LAMINATED BEAMS: SUMMARY REPORT

WESTERN ARCHRIB¹
1 9 8 6

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THIS IS A JOINT PUBLICATION OF THE CANADIAN FORESTRY
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ABSTRACT

Fifty-eight full scale flexural tests were performed on a structural glued-laminated beam product manufactured by Western Archrib from Alberta-grown Western Spruce and Lodgepole Pine.

Overall results indicate the product is comparable both in regard to bending strength and stiffness properties to the current C.S.A. grade of 20f-E Spruce/Lodgepole Pine glulam.

A size effect relating to bending properties was observed and recommendations for design are made.

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1.0. INTRODUCTION

Presently, Western Archrib purchases all of its laminating material in Douglas Fir from the United States. The higher initial costs of Douglas Fir are further aggravated by the present rate of U.S. exchange and added freight costs of \$50-\$60. per 1000 FBM. An alternative to the imported Douglas Fir, utilizing Alberta grown Spruce and Pine, would have significant economic advantages.

The objective of the research programme was two-fold:

1. To develop a simplified grade combination in Spruce and Pine which would permit the practical use of lumber presently produced in Alberta in manufacturing glued-laminated beams.
2. To establish for the new grade combination a specified strength and stiffness as defined in CAN3-086.1-M84: Engineering Design in Wood (Limit States Design) (1)

2.0. BEAM MANUFACTURE

Fundamental to the manufacture and design of laminated timber (glulam) is the selective placement of boards through the depth of cross-section according to their strength and stiffness properties. This characteristic of glulam known as the "Grade Combination" or "Lay-up" is intended to provide boards of high strength in those locations within the beam which develop high normal stresses due to their end-use. The net result is an efficient use of the raw material combined with optimum allowable design stresses allowing for safe, yet economical, use of glulam as a structural material. Therefore, in accordance with the objective of the test programme, the first step was to determine an appropriate grade combination for beam manufacture.

Based on both a literature search and an investigative tour of research and manufacturing facilities in West Germany and Norway, the following approach was developed. First, a limited number of beams (designated Series "A") would be produced in a grade combination based on a modified C.S.A. specification. The modifications included a greater emphasis on stiffness rating as an indicator of board strength and a modified outermost tension lamination requirement aimed at maintaining a manufacturing specification in line with the quality of lumber economically available from Alberta mills. Contingent on the results of Series "A" beam tests, the remainder of the lumber available (representing the vast majority of the total allocated for test beam manufacture) would be used to manufacture beams produced in accordance with an entirely new and simplified grade combination. It was intended that beams so manufactured (Series "B", "C", and "D"), comprising 46 of the total of 58 tested, would provide data on which the proposed new product would be based. Both grade combinations used are summarized in Table 1.

TABLE 1: MINIMUM LAY-UP REQUIREMENTS FOR TEST BEAMS

Series	MINIMUM LAY-UP REQUIREMENTS		
	ZONE	Minimum E-Value psi (MPa)	Minimum Visual Grade
A	Outer 1/7 Compression	1,600,000 (11,000)	¹ NLGA #2
	Remainder of Outer 2/7 Compression	1,400,000 (9,650)	¹ NLGA #2
	Inner 3/7	N/R	¹ NLGA #2
	Remainder of Outer 2/7 Tension	1,400,000 (9,650)	² CSA 0122 'C'
	Outer 1/7 Tension	1,600,000 (11,000)	² CSA 0122 'B'
B,C,D	Outer 1/6 Compression	1,600,000 (11,000)	² CSA 0122 'C'
	Inner 2/3	N/R	¹ NLGA #2
	Outer 1/6 Tension	1,600,000 (11,000)	² CSA 0122 'B'

Notes:

1. In addition, visual characteristics which either unduly hinder bonding or render the piece otherwise unacceptable for laminating were also excluded.
2. Ref. (2)

The simplified grade combination utilizes a three zone lay-up, similar to that which is currently used in Norway, with the added refinement of mandatory stiffness-rating of material used throughout the outer tension and compression zones.

It was believed that beams made in this way would exhibit a high degree of uniformity with respect to flexural strength and stiffness properties. As a function of the three zone lay-up, test beams for Series "B" through "D" were made in 6, 12, and 18 lamination depths, allowing for a comprehensive study of flexural strength properties over a range of commercially-used sizes. All test beams were produced from 2"x6" Western Spruce and Lodgepole Pine lumber, obtained from Millar Western Industries Ltd., of Whitecourt, Alberta, resulting in beams of 5 inch (127 mm) net width.

Overall beam manufacture was in conformance with the proposed Western Archrib Manufacturing Standard for Spruce/Pine Glulam.(3).

Table 2 presents a summary of pertinent dimensions and quantities for the test beams, Series "A" through "D".

TABLE 2: MANUFACTURING DATA

Series Designation	Total Number of Beams Produced	Number of Laminations 1-3/8"/Lam (35 mm/Lam)	Nominal Cross-Sectional Dimensions in. x in. (mm x mm)	Length	
				Overall Ft.-in. (mm x mm)	¹ Test Span Ft.-in. (mm x mm)
A	12	14	5"x19-1/4" (127 x 489)	27'-2" (8280)	25'-6" (7823)
B	16	12	5"x16-1/2" (127 x 419)	23'-6" (7163)	22'-0" (6706)
C	15	18	5"x24-3/4" (127 x 629)	34'-6" (10516)	33'-0" (10058)
D	15	6	5"x8-1/4" (127 x 209)	12'-6" (3810)	11'-0" (3353)

Note: 1. Test Span = 16 times beam depth.

3.0. TEST PROCEDURE

All 58 beam tests were conducted at the I. F. Morrison Structural Engineering Laboratory, University of Alberta. Testing was conducted in accordance with standard methods set forth in ASTM-D198-84.(4). During the course of the testing, measurements were taken to allow

the calculation of bending stress at failure (M.O.R.), Modulus of Elasticity (M.O.E.), gross density and moisture content. The test set-up is shown schematically and by photograph in Figures 1 and 2.

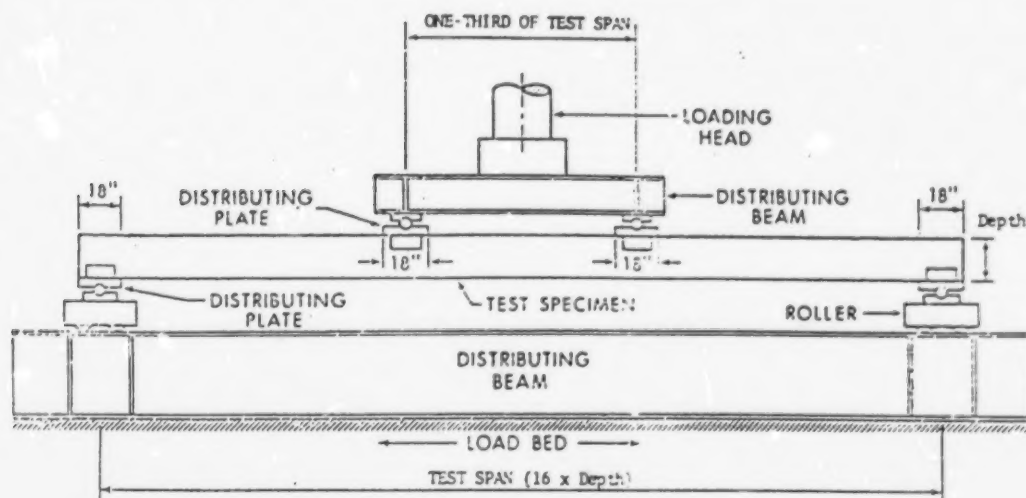


FIGURE 1: SCHEMATIC VIEW OF TEST SET-UP:

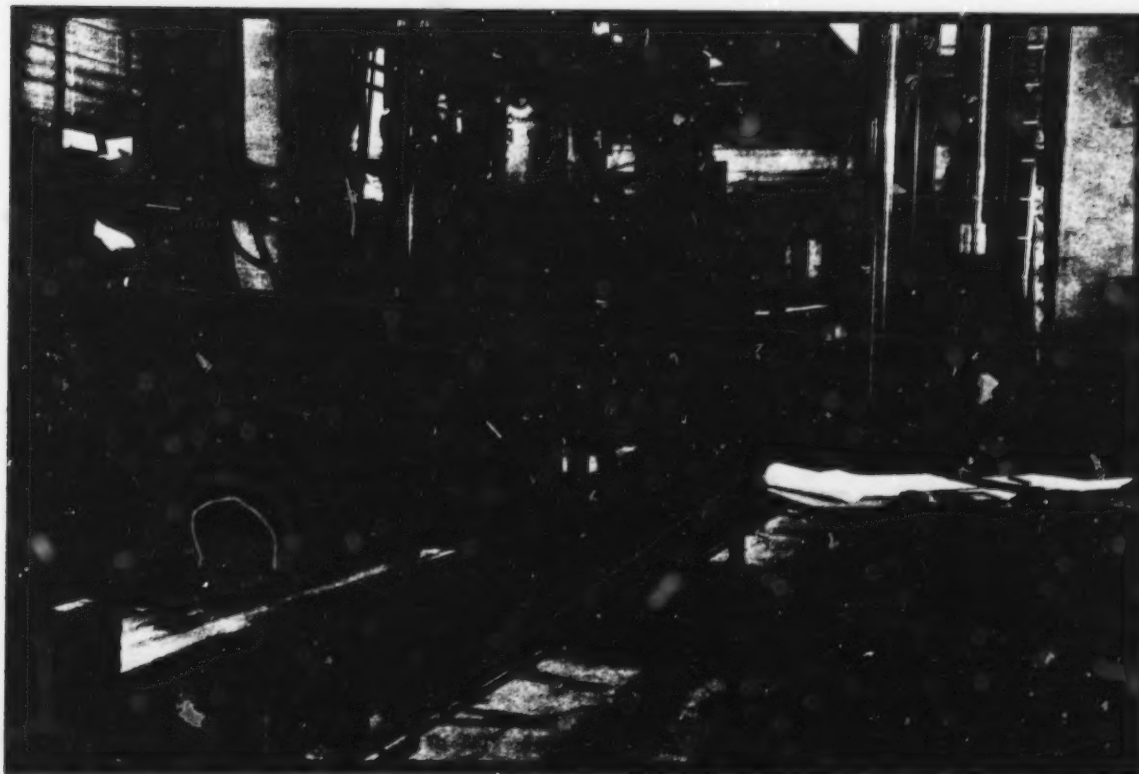


FIGURE 2: PHOTOGRAPH OF TEST SET-UP:

4.0. TEST RESULTS

The results of the 58 full-size beam tests are summarized in Tables 3A through 3D. Detailed data collected during the course of the testing is kept on file at Western Archrib, Alberta Research Council and the University of Alberta.

Measurements were taken to allow the calculation of the beam stiffness based on both the full span (E_f) and the shear free span (E_g).

The value of E_g is a measure of the true Modulus of Elasticity or "Young's Modulus". The value given by E_f represents an "apparent Modulus of Elasticity, which includes the effects of deformation due to internal shearing stresses. Both have been calculated from the test data according to standard formulae given in ASTM-198-84.

The term Modulus of Rupture (M.O.R.) relates to the level of outer fibre bending stress at failure. In the calculation of M.O.R. allowance has been made for the bending stress induced by the beam's self-weight. Accordingly, M.O.R. has been calculated as:

$$\text{M.O.R.} = \text{Bending Stress 1} + \text{Bending Stress 2}$$

Where:

Bending Stress 1 = Stress due to load applied by testing equipment

Bending Stress 2 = Stress due to self-weight

Unit weight was calculated from the weight of the beam just prior to testing and the beam dimensions.

The moisture content reported represents an average value for the beam based on a full cross-sectional sample taken from one end of the beam immediately following destructive testing.

TABLE 3A: SERIES "A" TEST RESULTS

Beam Number	Modulus of Elasticity $\times 10^3$ psi ^{1.}		Modulus o f Rupture psi	Moisture Content	Density lbs/cu.ft. ^{2.}
	E_f	$E_g^3.$			
1A	1452	-	5502	14.5%	30.1
2A	1469	-	5731	14.8%	30.3
3A	1447	-	6274	14.9%	30.1
4A	1507	-	5504	16.3%	30.8
5A	1526	-	4773	16.0%	30.9
6A	1464	-	4979	15.6%	30.5
7A	1420	-	6233	15.9%	30.9
8A	1500	-	4325	16.4%	30.4
9A	1476	-	5806	15.4%	30.6
10A	1442	-	5047	14.8%	29.5
11A	1546	-	5247	16.9%	31.1
12A	1568	-	5954	16.4%	30.8

- Notes:
1. 1000 psi = 6.894 MPA
 2. 1 lb/ft³ = 16.023 Kg/m³
 3. Missing data due to an inconsistency in measurement

TABLE 3B: SERIES "B" TEST RESULTS

Beam Number	Modulus of Elasticity $\times 10^3$ psi ^{1.}		Modulus of Rupture psi	Moisture Content	Density lbs/cu.ft. ^{2.}
	E _f	E _g			
1B	1407	1530	4531	13.7%	28.8
2B	1411	1471	5111	13.7%	28.1
3B	1380	1506	4371	14.2%	27.8
4B	1404	1478	4296	14.5%	28.8
5B	1384	1558	5001	14.2%	28.4
6B	1377	1447	4725	14.1%	29.5
7B	1408	1522	5716	14.8%	28.2
8B	1387	1475	4418	14.4%	28.7
9B	1375	1503	4321	13.9%	28.1
10B	1418	1550	4689	14.7%	29.1
11B	1452	1562	5113	14.9%	28.7
12B	1421	1512	4879	15.2%	28.4
13B	1564	1670	5934	13.9%	31.2
14B	1556	1590	5510	13.3%	30.6
15B	1435	1569	4540	14.3%	30.9
16B	1607	1796	6470	13.9%	31.5

- Notes:
1. 1000 psi = 6.894 MPa
 2. 1 lb/ft³ = 16.023 Kg/m³

TABLE 3C: SERIES "C" TEST RESULTS

Beam Number	Modulus of Elasticity $\times 10^3$ psi ^{1.}		Modulus of Rupture psi	Moisture Content	Density lbs/cu.ft. ^{2.}
	E _f	E _g			
1C	1480	1562	4664	13.6%	30.5
2C	1487	1569	5162	14.2%	30.3
3C	1481	1574	4528	14.5%	30.3
4C	1514	1556	5954	13.5%	30.1
5C	1529	1560	3930	14.0%	29.9
6C	1528	1627	5648	13.6%	29.9
7C	1472	1519	4825	12.8%	30.0
8C	1469	1538	4561	13.4%	30.2
9C	1454	1577	5262	12.7%	30.2
10C	1530	1636	5414	12.9%	30.6
11C	1475	1571	4711	12.9%	30.6
12C	1458	1490	4989	12.7%	30.2
13C	1512	1552	5846	13.8%	30.8
14C	1461	1492	4854	13.8%	30.8
15C	1507	1553	6427	13.7%	30.3

- Notes:
1. 1000 psi = 6.894 MPa
 2. 1 lb/ft³ = 16.023 Kg/m³

TABLE 3D: SERIES "D" TEST RESULTS

Beam Number	Modulus of Elasticity $\times 10^3$ psi ^{1.}		Modulus o f Rupture psi	Moisture Content	Density lbs/cu.ft. ^{2.}
	E _f	E _g			
1D	1579	1766	4737	13.3%	30.9
2D	1422	1473	5037	13.6%	30.3
3D	1451	1552	6244	13.4%	30.4
4D	1508	1623	6486	13.0%	30.2
5D	1448	1586	6074	13.3%	31.0
6D	1465	-	6171	13.2%	30.7
7D	1416	1541	5748	13.6%	29.9
8D	1397	1579	5511	13.4%	29.6
9D	1462	1624	5740	12.8%	29.3
10D	1362	1526	7282	12.4%	30.4
11D	1389	1588	5687	12.9%	29.0
12D	-	-	5417	13.4%	30.4
13D	1640	1796	6830	13.5%	31.8
14D	1535	1609	6015	13.8%	31.3
15D	1651	1676	6195	14.4%	30.2

- Notes:
1. 1000 psi = 6.894 MPa
 2. 1 lb/ft³ = 16.023 Kg/m³

5.0.

DISCUSSION OF RESULTS

Series "A" test results indicated it would be possible to obtain a product of equivalent flexural and stiffness properties to the current C.S.A. grade of 20f-E Spruce/Pine glulam with the adopted modifications. With this knowledge, test Series "B" through "D" were manufactured with the additional goal of simplifying the lay-up. Because these latter tests describe the performance of the new product, the remainder of the discussions and the final recommendations will deal only with the 48 beams forming Series "B", "C" and "D".

5.1.

SPECIFIED STRENGTH

The statistical analysis presented in the full report "Testing of Alberta Spruce and Pine Laminated Beams" (Himmelfarb, Cheng and Bach) (5) and directed at establishing strength and stiffness properties for design of a product made according to the new grade combination, is summarized in Table 4. For the purposes of that report the design parameter termed "Specified Strength" was defined statistically as: the lower 75 percent confidence limit on the estimate of the lower 5 percent level of population strength. The data presented in Table 4 suggests that an inversely proportional relationship exists between beam size and specified strength.

The concept of a size effect applying to flexural strength has been accepted for many years by the American Institute of Timber Construction (A.I.T.C.). The formulation given by American design specification AITC 117-85(7) can be expressed as:

$$\text{Specified Strength} = \left[\begin{array}{c} \text{Specified Strength} \\ \text{at a reference depth} \\ \text{of 12 inches} \\ \text{(304 mm)} \end{array} \right] \times C_f$$

$$\text{Where } C_f = \left[\frac{12}{d} \right]^{\frac{1}{9}} \quad d = \text{Actual beam depth in inches}$$

This formulation was used in an attempt to quantify the trend observed in the test data. A mathematical model, using a specified strength of 2000 psi (29 MPa) at a reference depth of 12 inches (304 mm) and the C_f factor given above, was compared to the specified strengths calculated from the test data at the various depths tested. This comparison demonstrated good agreement between

TABLE 4: STATISTICAL PARAMETERS

Series Designation	MODULUS OF RUPTURE DATA			MODULUS OF ELASTICITY DATA			
				E_f		E_g	
	Mean psi (MPa)	C.O.V.	Specified ¹ Strength psi (MPa)	Mean psi (MPa)	C.O.V.	Mean psi (MPa)	C.O.V.
D	5,945 (40.99)	11.0%	4,643 (32.01)	1,445,400 (9,966)	4.2%	1,585,930 (10,935)	4.9%
B	4,678 (32.25)	6.7%	4,029 (27.78)	1,402,000 (9,666)	1.6%	1,509,625 (10,409)	2.4%
C	5,096 (35.14)	13.2%	3,758 (25.92)	1,490,000 (10,273)	1.8%	1,558,000 (10,742)	2.6%

Note: 1. Determined using factors for one-sided tolerance limit for normal distributions. Taken from ASTM 2915-84. (6)

the predicted and observed levels of specified strength. The test data, as shown in Table 5, exhibited a somewhat greater specified strength (+5.9%) at the smallest depth tested and a slightly lower specified strength (-3.1%) at the largest depth tested when compared to the model.

5.2.

MODULUS OF ELASTICITY

Inspection of the M.O.E. data revealed no relationship between beam size and beam stiffness. The small differences reported

TABLE 5: SPECIFIED STRENGTH

Series Designation	Mean Depth of Test Beams Inches (mm)	Specified Strength Predicted by Model (F _b) psi (MPa)	Specified Strength Based on Test Data (F' _b) psi (MPa)	Percent Difference
D	8.27 (210)	4383 (30.22)	4643 (32.01)	+ 5.9%
B	16.50 (419)	4058 (27.98)	4029 (27.78)	- 0.7%
C	24.84 (631)	3878 (26.74)	3759 (25.92)	- 3.1%

between the mean M.O.E. values of Series "B" through "D" likely represent variations which are to be expected in practical manufacture. On the basis of a statistical analysis given in the full report, a summary of the beam stiffness properties is given in Table 6. The tabulated values indicate that the full span-E is 4.3% lower than the true M.O.E. as estimated by the shear free span-E, which is as would be expected. Further, the M.O.E. data exhibits an extremely low coefficient of variation, indicative of well controlled manufacture.

Traditionally, the Modulus of Elasticity value used in design has been based on the lower 95% confidence limit of the mean as established from test results. In the case of the data presented in this report, this value would be 10,000 MPa (1,465,000 psi) or 10,550 MPa (1,530,000 psi) depending on whether full span or shear free calculations were used.

TABLE 6: MODULUS OF ELASTICITY

Property Measured	Mean psi (MPa)	Coefficient of Variation	Lower 95% Confidence Limit on Mean psi (MPa)
Shear Free Span 'E'	1,550,100 (10,687)	3.8%	1,530,000 (10,549)
Full Span 'E'	1,483,100 (10,226)	3.7%	1,465,000 (10,100)

5.3.

ADDITIONAL OBSERVATIONS

In addition to the test results, a number of significant observations can be made:

First, failure invariably initiated from the outermost tension lamination within the middle third of the beam (i.e. the zone of maximum and constant normal stress). Although failure was, in some cases, associated with the location of an end joint, in no instance could the failure be attributed to an inadequate quality of joint. Since in all beams an end joint was intentionally located within the outermost tension lamination in the zone of maximum normal stress, it can be stated that the quality of end joints was satisfactory. A typical failure is shown in Figure 3.

Secondly, the coefficient of variation calculated from the M.O.R. test data ranged from 6.7% to 13.2%. In comparison to the variability in M.O.R. data reported in other research papers dealing with full scale beam tests, this result confirms the belief that an extremely uniform product has been developed.

Finally, the moisture content of the test beams ranged from 12.4 percent to 16.9 percent with an average value of 14.1 percent (Std. Dev. = 1.04) which is representative of the upper range of Dry Service Conditions.



FIGURE 3: TYPICAL FAILURE

6.0.

CONCLUSIONS

The beams provided for testing have been manufactured in accordance with Western Archrib's Manufacturing Standard for Spruce/Pine Glulam. The low variability demonstrated with respect to bending strength and, in particular, Modulus of Elasticity, and the absence of end joint failures, indicates that a uniform, well made structural product has been produced. The grade combination used achieves the objective of simplifying manufacture by reducing the number of grades from six to three and utilizes grades of Spruce and Pine that are available from Canadian mills.

Test data confirm the existence of a size effect related to bending strength. The trend observed can be closely approximated by the size factor formulation given by A.I.T.C. Design Specifications.

7.0.

RECOMMENDATIONS

From the statistical analysis of the strength data, a specified strength in bending of 29.00 MPa (4,200 psi) at a reference depth of 304 mm (12") is recommended for Dry Service Conditions. This compares directly to the specified strength value for the C.S.A. 20f-E grade of Spruce/Lodgepole Pine glued-laminated timber given in CAN.3-086.1-M-84: Engineering Design in Wood. General design provisions for the calculation of moment resistance as set forth in CSA 086.1-M84 are applicable.

The size effect on strength properties noted in this study should be accounted for in design. It is recommended that the standard formulation for size factor given by A.I.T.C.-117-85, and used throughout the United States for all glued-laminated timber design, be used.

A Modulus of Elasticity value for design of 10,300 MPa (1,500,000 psi) is recommended. Again, this compares directly to the value published in CSA 086.1-M84 for the C.S.A. 20f-E grade of Spruce/Lodgepole Pine glued-laminated timber.

8.0.

COMMERCIAL SIGNIFICANCE

Test data confirm that glulam beams manufactured from Alberta grown Spruce and Pine can compete directly on the basis of strength with the existing C.S.A. grade of 20f-E Douglas Fir glulam. As a result of the test programme, C.M.H.C. approval of glulam made in

accordance with the Western Archrib Plant Standard and marketed under the trade name of "WESTLAM" has been received.

Aside from the anticipated marketing advantages resulting from a lower cost raw material, glulam made from Alberta Spruce and Pine has shown distinct, but previously unrecognized, manufacturing advantages in its ease of framing, finishing and handling. Further, the Spruce and Pine lumber used in manufacture tends to have small, tight knots and is lighter in colour when compared to Douglas Fir. It is expected that beams produced from this lumber will be comparable, if not preferable, in appearance, to beams made from Douglas Fir.

Western Archrib now firmly believes that Spruce/Pine glulam will be a reliable, economically attractive structural product that will, in a very short time, grow to represent a significant proportion of the Company's annual production.

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